Estimating the nutritive value of cereal crop residues: Implications for developing feeding standards for draught animals

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SUMMARY

ANALYTICAL METHODS *for the determination of the nutritive value of cereal crop residues are reviewed, the emphasis being given to methods used to estimate total plant cell wall and its digestibility. Examples are given of the accuracy of different methods in determining digestibility and of the factors affecting it. Various management practices for feeding cereal crop residues to draught animals are highlighted.*

INTRODUCTION

Approximately 15% of the arable land in sub-Saharan Africa is cultivated by smallholders using animal traction (ILCA, 1981). Obtaining adequate feed for draught animals is one of the main problems these farmers face, especially at the end of the dry season before cultivation starts.

Cereal crop residues constitute a major feed resource for working animals in most African countries; grassland vegetation, stored hay and fibrous byproducts, such as pulses, oil plants, sugarcane, roots and tubers, are less important. Few smallholders have easy access to, or can afford, concentrate feeds. The quantity and quality of crop residues available, and the farmers' feeding strategies, thus have a direct effect on the nutrition of draught animals.

In 1981, an estimated 236 million tonnes of cereal crop residues were produced in Africa. Nearly 70% of the residues were derived from cereals, with maize, millet and sorghum providing the largest portion in sub-Saharan Africa. Throughout the continent, the amount of crop residues produced averaged 1.5 t of feed per livestock unit per year (Kossila, 1984).

In West Africa, draught animals (cattle, donkeys and horses) commonly receive diets composed of maize, millet and sorghum stover, rice straw, groundnut and bean haulms, and maize and millet cobs. These residues may be fed separately or as a mixture, and sometimes they may be supplemented with cowpea or groundnut hay or with agro-industrial byproducts, such as cottonseed and groundnut cake or brewer's grains.

Farmers in the Ethiopian highlands have a tradition of conserving crop residues from teff *(Eragrostis tef),* barley, wheat and sorghum. In Kenya, oxen are fed stored maize stover, and pigeon pea and cowpea residues (Tessema, 1984). Maize, millet and sorghum stover are the main crop residues available for working animals and other livestock in Botswana and

Tanzania (Mayer, 1983; Urio, 1985). In Lesotho, Malawi, Zambia and Zimbabwe, maize stover and other cereal crop residues provide the bulk of the diet fed to draught animals (Chabala, 1984; Molapo et al, 1984; Shumba, 1984; Watson et al, 1984).

Many researchers in Africa and elsewhere (including Reh, 1982; Goe, 1983, 1987; Upadhyay et al, 1983; Mathers, 1984; Mathers et al, 1985; Bamualim and Kartiarso, 1985; Ibrahim, 1985; Lawrence, 1985; Wanapat, 1985; Abiye Astatke et al, 1986; Pearson, 1986; Soller et al, 1986) have shown interest in determining energy requirements of, and/or developing feeding standards for, working animals, particularly cattle.

A comparison of five analytical systems in terms of their advantages and disadvantages is given in this paper. For a detailed description of the techniques reviewed, the reader is referred to cited literature. It should be noted that while the discussion in this paper focuses on draught cattle, the analytical methods and the crop residue management practices highlighted are relevant to other livestock, e.g., sheep and goats, as well.

NUTRITIVE VALUE OF CEREAL CROP RESIDUES

Cereal crop residues are deficient in nitrogen and have a high cell-wall content. Both factors reduce their intake and digestibility. Supplementation with non-protein nitrogen or high-protein feedstuffs may improve intake and digestibility, but cannot always compensate for other anti-nutritional factors, such as high fibre content and presence of phenolic compounds (Donefer et al, 1969; Ørskov and Grubb, 1978; Chesson and Ørskov, 1984). It is necessary to study the factors that limit energy intake from cereal crop residues, because large increases in animal productivity can be achieved by relatively small increases in digestibility and intake.

The physical properties of cereal crop residues are to a large extent determined by the characteristics of their cell walls (Van Soest, 1967). Cell wall polysaccharides (cellulose and hemicellulose) account for more than 70% of the dry matter in cereal crop residues and are a major energy source for the microbial production of protein and volatile fatty acids in the rumen.

However, cell-wall content is negatively correlated with intake. High cell-wall content increases rumination time and is associated with decreased efficiency of conversion of metabolisable energy to net energy. The ability of the rumen microorganisms to digest cell-wall polysaccharides is limited by the presence of phenolic and other aromatic compounds (Hartley, 1981).

ANALYTICAL METHODS

Detergent system

No single chemical analysis currently exists which is able to describe the biodegradability of cell-wall matter by rumen micro-organisms. Such a description may, however, be possible by combining the results of a sufficient number of analyses (Van Soest, 1982).

The detergent system of analysis, which is described below, was designed to replace the proximate analysis system in estimating the nutritive value of fibrous feeds. The major problem of the proximate analysis system is that it does not separate feeds into meaningful nutritive fractions and results in losses of cellulose, hemicellulose and lignin and other significant components of fibre (Van Soest, 1967; Van Soest and Robertson, 1980). In comparison, the detergent system is based on the separation of feeds into fractions with uniform or non-uniform nutritive availability, as defined by the Lucas test (Lucas et al, 1961; Van Soest, 1967).

The test for uniform nutritive availability involves an analysis of the digestible amount of a feed fraction regressed on the percentage of the fraction in feed. For feed fractions that are represented in faeces by indigestible amounts of feed, microbial debris and endogenous excretions, the slope represents true digestibility and the negative intercept estimates the endogenous secretions as a percentage of intake. A feed fraction with uniform nutritive availability has a regression equation with a low standard error and an intercept less than or equal to zero. A high correlation coefficient is not indicative of uniform nutritive availability.

Cell contents and protein are feed fractions which usually have uniform nutritive availability. Both these feed fractions have true digestibility greater than 90% and negative intercepts. Lignin is a nutritionally uniform feed fraction with a true digestibility not significantly different from zero.

Cell wall, cellulose and hemicellulose are feed fractions with non-uniform nutritive availability. They have regression equations with high standard errors. Negative intercepts in this case have no biological meaning because there can be no endogenous excretion of cell-wall carbohydrates.

Neutral-detergent fibre

The separation into uniform and non-uniform feed fractions is achieved by neutral-detergent extraction. The technique separates cell contents (uniform) from the cell wall (non-uniform) in feeds, and bacterial and endogenous debris from undigested cell wall in faeces (Mason, 1979). Neutral-detergent fibre (NDF) consists of cellulose, hemicellulose and lignin, which are major cell-wall fractions. Biogenic silica and pectins are not recovered in NDF, but soil silica, heat-damaged proteins and tannin-protein complexes are.

Acid-detergent fibre

Acid-detergent fibre (ADF) is a preparatory extraction for the determination of cellulose, lignin, total silica and heat-damaged protein (Van Soest and Wine, 1967).

An estimate of heat-damaged protein (Maillard products) is made by a determination of nitrogen in the ADF, using the Kjeldahl method. The Maillard reaction is a polymerisation of proteins with carbohydrates (mainly pentoses in hemicellulose) caused by heating due to industrial processes or fermentation.

Heat-damaged proteins are indigestible. Oilseed meals usually have low ADF nitrogen when oils are extracted by press or solvent without heating. But other byproducts, such as brewer's grains, tomato pomace and byproducts from the extraction of essential oils, can have high ADF nitrogen (Wohet et al, 1981).

Oven drying at temperatures above 60°C to enable feed analysis can result in heat-damaged protein and increased fibre and lignin values. Lignin is a phenolic polymer which lowers the digestibility of cell-wall carbohydrates. Acid-detergent extraction removes all proteins except those that are closely associated with lignin or are damaged by heat. Treatment of ADF with 72% sulphuric acid removes cellulose. The organic residue is mostly lignin unless the feed contains heat-damaged protein or cutin. Sequential treatment of ADF with potassium permanganate and 72°/o sulphuric acid leaves an organic residue of cutin.

Silica is recovered in ADF ash treated with hydrobromic acid to remove other acid-insoluble minerals. Biogenic silica lowers dry-matter digestibility between 1.4 and 3.0 units for each unit of silica, either by inhibiting cell-wall digestion or by acting as a diluent (Van Soest, 1982). Soil silica, which is also recovered in ADF ash, has no effect on digestibility of other feed components.

Attempts to use ADF as a replacement for crude fibre in digestibility predictions are erroneous and beset by the same problems as the proximate analysis system. This is because such use of ADF is founded on statistical associations which have very little biological meaning. The intended use of ADF is as a preparative residue, not as a digestibility predictor (Van Soest and Robertson, 1980).

Microfibre apparatus

Research groups in developing countries have been slow to adopt newer methods of forage fibre analysis (such as the neutral-detergent system) because of the high cost of reagents and apparatus. ILCA's Nutrition Unit has developed a microfibre apparatus which costs a fraction of the amount of the conventional fibre apparatus and uses one tenth of the amount of reagent. Also, results demonstrate that the microfibre method is comparable to the conventional NDF method and has the same range of error (± 2 units) (Reed, 1984).

ESTIMATING DIGESTIBILITY

Digestibility ranks next to intake in importance for determining the nutritive value of feedstuffs. There are four general methods which can be used to estimate the digestibility of feed resources:

- Enzyme methods, which use fungal cellulases after pretreatment with proteolytic enzymes or detergents;
- Prediction equations, which are based on chemical analysis of cell wall and lignin;
- In vitro techniques using rumen microbes; and
- Cloth-bag methods.

Enzyme systems

Laboratory methods which rely on incubation with commercially available enzymes (fungal cellulases) to estimate digestibility of cereal crop residues and forages are inadequate to develop relevant feeding recommendations for draught animals in the tropics. The major disadvantages associated with such systems are the variable quality of commercially produced enzymes, inability of the enzyme to adapt to a substrate, completeness[1] of the enzyme component and poor cell-wall digestibility (McQueen and Van Soest, 1975; Dowman and Collins, 1977; Van Soest, 1982).

[1]Purified cellulase preparations are less effective in digesting cell-wall carbohydrates than less purified enzyme preparations which have enzymes that digest carbohydrates and other cellulose and may also digest protein.

Cellulase methods underestimate the digestibility of fibrous feeds, so such values must be corrected by regression equations using in vivo values. However, there is a large variation in regression coefficients obtained by different research groups, probably due to the type of feed analysed and the method employed. This large variation in coefficients indicates an inconsistent biological relationship between in vivo digestion and degradability by cellulase.

The limited reliability of cellulase methods to predict accurately the nutritive value of cereal crop residues was demonstrated in an ILCA study (ILCA, 1985). Two cellulase methods were used to determine fibre digestibility in 27 straw samples taken from farms in the Ethiopian highlands keeping draught animals. These were:

- Method 1: Pretreatment with pepsin/ hydrochloric acid (HCI) for 48 hours followed by incubation with cellulase for 48 hours (Goto and Minson, 1977); and
- Method 2: Incubation of the neutral-detergent fibre fraction of the forage with cellulase for 48 hours (Hartley et al, 1974).

Fibre digestibilities by these two methods were compared with fibre digestibilities obtained for the same samples by the action of rumen micro-organisms in vitro (Goering and Van Soest, 1970). The mean in vitro fibre digestibility was 36.9 and 22.3 units greater than the estimates from Method 1 and Method 2, respectively. Cellulase methods are thus less effective than rumen micro-organisms in digesting fibre from cereal crop residues. Nefzaoui and Vanbelle (1985), who reviewed much of the literature comparing the accuracy of enzyme methods with in vitro techniques, arrived at a similar conclusion.

Summative equation

The summative equation is based on the logic of the Lucas test for uniform nutritive availability. Unlignified cellular contents have an assumed mean true digestibility of 98%. Cell-wall digestibility is estimated by regression on the lignin content of ADF (Goering and Van Soest, 1970; Van Soest, 1982). The sum of the digestible cell wall and digestible cell contents is then an estimate of true digestibility.

Apparent digestibility is obtained by subtracting an estimate of metabolic faecal loss from true digestibility. A correction for the effects of silica on digestibility is applied when opaline biogenic silica is greater than 2%.

In Table 1, the summative equation for 34 samples of straw fed to draught oxen in the Ethiopian highlands gave the same estimate of apparent digestibility as the Tilley and Terry in vitro method (Tilley and Terry, 1963). A metabolic faecal loss amount of 12.9 units and a silica correction factor of 1.4 were used in the summative equation.

Table 1. *Comparison of the summative equation and the Tilley and Terry in vitro method in estimating apparent digestible dry matter of 34 straw samples.*

Apparent digestible dry matter				Paired t-test difference[1]	
Summative equation		Tilley and Terry in vitro			
Mean	SD	Mean	SD	Mean	SD
54.4	2.4	54.3	3.9	0.04	2.8

[1] The difference between means is not significant ($P>0.05$).
Source: Goe (1987).

Fibre quality as affected by lignin and silica is an important aspect in the use of cereal crop residues. Table 2 shows that NDF usually exceeds 70% of the dry matter, with some variation between species and plant fractions. The lignin content of cereal crop residues is low compared with that of residues from dicotyledons, thus potentially, digestible fibre in cereal crop residues is greater. However, this greater digestibility may not be reached because nitrogen and other microbial nutrients are limiting.

Table 2. *Nitrogen (N), neutral-detergent fibre (NDF), acid-detergent fibre (ADF), lignin (LG), silica (SIL) and apparent digestible dry matter (ADDM) in cereal crop residues fed to livestock in Africa.*

Residues	N	NDF	ADF	LG	SIL	ADDM[1]
	%					
Maize	0.81	75.5	51.3	4.8	5.2	57.2
Maize upper stalk	0.41	75.8	44.8	4.8	2.0	58.6
Maize leaf sheath	0.33	83.9	47.4	4.8	2.2	57.1
Maize tassel	0.79	82.3	46.2	7.9	5.1	38.8
Sorghum leaf sheath	0.25	79.9	53.2	6.1	3.0	53.5
Millet leaf sheath	0.32	74.9	47.8	4.1	1.9	64.2
Teff straw	0.51	73.5	44.2	4.2	3.3	60.0
Wheat straw	0.41	72.2	54.3	5.9	4.5	55.4
Rice straw	0.77	71.0	54.2	3.1	16.2	54.9
Rice hulls	0.66	80.0	80.8	15.6	22.9	11.3

[1] Estimated by the summative equation.
Sources: Powell (1985); Reed and Van Soest (1985).

In vitro systems

In vitro rumen systems are the most accurate methods for estimating the digestibility of feedstuffs, because they utilise micro-organisms and enzymes which are sensitive to undetermined factors that influence rate and extent of digestion (Van Soest and Robertson, 1980; Van Soest, 1982).

Probably the most commonly used fermentation system is that developed by Tilley and Terry (1963). The method involves two stages: digestion with rumen micro-organisms for 48 hours, followed by a 48-hour digestion with pepsin in acid of about pH 2. The residue is composed of undigested plant cell wall and bacterial debris, and the results are directly comparable to in vivo apparent digestibility (Van Soest, 1982).

A modification of the Tilley and Terry system replaces the second-stage pepsin digestion with a neutral-detergent extraction which dissolves all microbial matter (Van Soest, 1982). The values obtained are estimates of true digestibility. The modification also allows estimation of cell-wall digestibility, provided that the NDF content of the sample is known. The modified procedure is as precise as the original Tilley and Terry system, has a lower analytical error and requires about half the time to complete (Van Soest and Robertson, 1985).

In vitro systems are more time consuming than chemical methods, and the digestibility values obtained are affected by problems in end-product measurement of microbial fermentation, i.e. cells, fermentation acids and gases. Moreover, access to fistulated animals to provide rumen inoculum, and close monitoring of their health, are necessary.

Cloth-bag method

Cloth bags made of nylon or Dacron and inserted into the rumen through a fistula, have been used in place of in vitro fermentation systems to estimate digestibility of feedstuffs (Kempton, 1980; Ørskov et al, 1980; Ørskov, 1988). This method gives, without using reagents, a simplified interpretation of the degradability of feedstuffs, as may be required for initial screening or ranking of a series of samples in agronomic trials.

The method requires that the bag be placed fairly accurately near the bottom of the rumen, and the porosity of the cloth as well as the ratio of sample weight to surface area of the bag need to be controlled. Cloth-bag digestibilities are subject to the same problems in end-product measurement as in vitro methods (Van Soest, 1982). The cloth used for the bags is expensive, difficult to obtain and must be replaced frequently due to wear. And, as noted for the in vitro methods, the health status of the fistulated animal must be maintained.

Another disadvantage of the cloth-bag method is the difficulty of separating the residues into indigestible feed and microbial fractions after removing the bag from the rumen. A comparison of in vitro and cloth-bag digestibilities of barley straw was made using three treatments of the residue after fermentation (Table 3). The treatments were:

- collection of the entire residue (no treatment),
- digestion of the residue with pepsin/hydrochloric acid as in the original Tilley and Terry method, and
- extraction of the residue with neutral detergent.

Table 3.*Comparison of 48-hour in vitro and cloth-bag digestibilities of barley straw, using three treatments of the residue after fermentation.*

Treatment	48-hour digestibility (%)				Significance of observed difference
	In vitro		Cloth bag		
	Mean	SD	Mean	SD	
None	49.2	5.2	52.9	10.1	NS[1]
Pepsin	56.2	5.4	56.1	8.4	NS
Neutral detergent	69.0	6.0	60.3	7.1	P<0.001
NDF digestibility[2]	58.3	6.2	46.5	7.2	P<0.001

[1] NS = not significant.
[2] Digestibility of the fibre fraction calculated by dividing the residual NDF from either the in vitro or the cloth-bag system by the amount of NDF in the sample, substracting the value from 1 and multiplying by 100.
Source of samples from seven barley varieties: B.S. Capper, ILCA, Debre Zeit, Ethiopia.

There was no difference between the in vitro and cloth-bag methods when the complete or pepsin-treated residue was used as the numerator in the calculation of digestibility. However, when the neutral-detergent residue was used, there was a large and highly significant difference ($P < 0.001$) between the two methods. This difference was caused by the greater digestibility of neutral-detergent fibre in the in vitro technique.

The difference between pepsin-treated residue and residual neutral-detergent fibre is an indication of the microbial mass present. This difference was 12.8 units for the in vitro technique and only 4.2 for the cloth-bag method, the first value being very close to the difference expected between true and apparent digestibility in vivo.

These results suggest that the microbial colonisation of bags is lower than that required for effective fibre digestion. Caution should, therefore, be used when estimating the energy value of straw by the cloth-bag technique and when comparing the nutritive value of different cereal crop residues since fibre digestion is the single most important factor in determining their nutritive value.

The results of the cloth-bag method are much less repeatable and more difficult to interpret than those of the Tilley and Terry system or the modified neutral-detergent extraction (Goering and Van Soest, 1970). Nevertheless, using cloth bags of controlled pore size (30 microns being about optimal) can be very useful in measuring in vivo rates of digestion (Van Soest, 1982).

Selecting the appropriate analytical system

Several analytical systems used to estimate the nutritive value of crop residues have been discussed. Which of these systems is selected as appropriate for use in national institutes will ultimately depend on available facilities and funding, the objectives of the research, the accuracy required and the types of feed resources under study. All systems require well-trained technical staff.

The use of enzyme (cellulase) methods is not recommended because of their inability to estimate accurately the nutritive value of cereal crop residues. Similarly, the use of cloth-bags to estimate the digestibility of feedstuffs is cautioned against. If a national research institute has the resources to invest in maintaining fistulated animals and acquiring materials for cloth-bag trials, it could probably also obtain the necessary laboratory apparatus and reagents to carry out in vitro or chemical analyses, both of which will allow a more accurate prediction of nutritive value.

Used for cereal crop residues or a mixture of forages, the summative equation is superior to other regression systems because it allows a larger number of samples to be analysed in a shorter period of time than the in vitro systems (Van Soest, 1982). It provides comparable results to in vitro methods and also has the advantage of not needing fistulated animals. However, for a single measurement of digestibility, regardless of the type of feedstuff involved, well designed in vitro fermentation systems will provide the most reliable results.

Where researchers only infrequently have the need to estimate the digestibility of feedstuffs and do not have the financial and human resources to maintain an adequate nutrition laboratory, it would probably be more appropriate to send samples to another national agricultural research institute which has the capability to carry out the required analyses.

MAXIMISING THE USE OF CROP RESIDUES

Cereal crop residues comprise the bulk of feed available in Africa for draught animals and other livestock. If these feed resources are to be used to their maximum potential, then some knowledge of their nutritive value, coupled with improved feed management, is necessary.

Variation in digestibility

Large variations in digestibility can occur among or between different types or varieties of cereal crop residues. For example, the in vitro organic matter digestibility (IVOMD) of 26 improved varieties of sorghum grown in Ethiopia was found to range from 38.3 to 55.2% (Reed et al, 1986). Cereal crop residues (mainly barley and wheat straw) fed to working oxen in the Ethiopian highlands had IVOMD values of 45 to 60% (Goe, 1987). Several other researchers have reported large variations in IVOMD of cereal crop residues grown in Europe, the United States and Australia (Nicholson, 1984).

Rations based on cereal crop residues with moderate to high digestibility (i.e. above 50%) can provide draught animals supplemented with low levels of nonprotein nitrogen (NPN) with the energy required for maintenance and work (Soller et al, 1986). When, however, digestibility is below 50%, intake will be inadequate for maintenance and work even with NPN supplementation.

The various plant parts of cereal crop residues, but especially stovers, have different digestibilities (Hacker and Minson, 1981; Powell, 1985). When given the choice, livestock first select the most palatable fractions, i.e. leaves and the upper part of stalks (Powell, 1984). This has implications for how crop residues are conserved and fed, and what approach should be used in carrying out nutritive analyses. If, for instance, the analyses include plant parts that are not usually eaten, the values obtained will not be representative of the actual nutritive value of feed intake.

Management of crop residues

In a major study of the use of cereal crop residues on smallholder farms in sub-Saharan Africa, McIntire et al (1989) found that grazing *in situ* is the dominant form of use throughout the continent, except in the densely populated highlands.

The nutritive quality of crop residues declines the longer they remain in the field. The most nutritive parts – leaves and the upper part of the stalk – are lost due to drying, wind damage and shattering. Turning animals onto harvested fields allows for selective grazing of plant parts, but there is also substantial wastage of the residue by trampling, in some cases between 40 and 50% (Chandler, 1984; Tessema, 1984). Even when stovers are stored and fed as whole stalk and leaves without chopping, wastage is high and intake low (Said and Wanyoike, 1987). Thus, cereal crop residues represent a feed resource with a potential that is not fully exploited on many smallholder farms.

Improved methods of storing can help maintain the initial quality of crop residues longer. But how feasible is it to introduce alternative methods? Transporting cereal crop residues to the place of storage involves additional labour, and the method of storing will change depending on the physical form of the residue. Because of their bulkiness, maize, millet and sorghum stovers are often stacked or bundled and left in the field, to be either transported to the homestead later or fed directly from the stack. In contrast, barley and wheat residues are threshed into small pieces, which makes their handling and storage easier.

The utilisation of crop residues can be improved in several ways. In the case of residues with large variations in digestibility among plant parts, increasing the amount of feed on offer to two to three times the amount consumed will allow the animal to select a better diet. The diet can be supplemented with brans and millings, oilseed cakes, legumes and fodder from multipurpose trees. Growing cereals and legumes in mixed stands will also increase the overall feed value of crop residues. A climbing forage legume which remains intact on the stover at the time of harvest can enhance the feeding value of the stover through a higher crude protein content (Dzowela, 1987). Improved tillage methods, such as surface drainage of crops grown on Vertisols, can result in higher yields of crop residues, allowing farmers to feed them to animals longer into the dry season (Jutzi, 1988). Chemical treatment of residues is not at present appropriate for the smallholder in Africa.

While certain management methods can increase both the quality and intake of crop residues, farmers' acceptance of even the simpler techniques, such as stripping of leaves, topping after maturity, chopping, and storage to preserve quality material, has been minimal because of the additional labour required and the low visibility of return (McDowell, 1988). In some instances, the management of crop residues by farmers may be adequate, but limited production of feed supplements, and the high cost of their transportation and handling, ultimately result in less efficient use of crop residues (Scarr, 1987). Genetic variation in the quality of crop residues also needs to be addressed, and this calls for greater cooperation between plant breeders and animal nutritionists.

Current use of cereal crop residues by smallholders should be examined prior to attempting to introduce alternative methods of management or allocation. Few on-farm studies have been carried out in Africa to determine the utilisation of cereal crop residues by working animals throughout the year and estimate the changes in nutritive value during storage (Mayer, 1983; Goe, 1987).

Quantitative data on the availability of crop residues on farms in relation to livestock numbers are limited (van Raay and de Leeuw, 1971; Powell, 1985). Further research is warranted to determine crop residue availability by type of crop, cropping intensity, degree of crop–livestock interaction and farmers' access to feed supplements. Simple techniques exist to estimate this parameter (Kossila, 1988).

In areas where human population pressure is bringing about land fragmentation, the management of crop residues will inevitably change. Growing competition for land between food and forage crops, but also draught, meat, milk and manure production, will ultimately dictate the extent to which alternative management practices are adopted by farmers.

For example, in some of the more densely populated highland areas of sub-Saharan Africa, where cows are kept for milk or oxen for draught, farmers are compelled to restrict grazing, and to harvest, store and selectively feed crop residues (McIntire et al, 1989). However, stall-feeding of crop residues deprives the land of manure. The division of responsibilities within the household for oxen (which are usually tended by the farmer) and other livestock (which may be the wife's responsibility) also needs to be investigated, because the best overall use of feedstuffs could, in fact, bring about conflicts in household relationships (Simpson and McDowell, 1986).

CONCLUSION

The intrinsic nutritive value of cereal crop residues can have a large effect on animal performance in response to protein and NPN supplementation. Reliable estimates of the nutritive value of cereal crop residues are necessary if these feed resources are to be used more efficiently. The analytical systems described in this paper can assist researchers to obtain such estimates and develop appropriate guidelines for feeding draught animals. The discussion of current management practices will, hopefully, prompt research on alternative methods of utilising crop residues.

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